ESA21
Environmental Science Activities for the 21st Century

Energy: Synthesis and Analysis

Energy Use in the Home

Convection

The average household spends over $1,300 a year for energy to run the many devices found in the home[1]. In this week's lab, we are going to investigate ways to save both energy and money that will not seriously impact your current lifestyle, i.e. you can keep watching as much television as you like, but you might want to put on a sweater to do it. In order to do this, we are going to have to use the measurements of our homes that we made two weeks ago.

Last week, we studied how different materials affect the amount of heat flow by conduction. This was important, since heat conduction is one of the primary ways that energy is lost in a home. Another method by which heat is flowing into or out of our homes is convection. Convection is heat transport by movement and mixing. When we open the doors to our homes, hot and cold air are allowed to mix, and heat is convected. Even when doors or windows are not open, there is convection occurring through any cracks or breaks in our windows, walls, doors, ceilings, and floors. We often notice this convection occurring on very cold, windy days. You will often find a blast of cold air hitting you when you walk by electrical outlets or windows on such days, a sign that your house is not airtight.

Of course, as air from the outside is coming into your home, the air inside of your home is going outside. Over time, the total volume of air in your home will be completely replaced with air from the outside. While this is good from the standpoint that stale, possibly toxic air is leaving your home, it is bad from an energy standpoint since your heating/cooling system will have to come on to bring this air temperature back to the prescribed setting. In a new, well-built home, the number of openings in your home allows this air exchange to occur over a period of about 2 hours. In older homes that have developed more cracks, this amount of time can be much shorter. For instance, in very old, poorly maintained homes, it might take as little as 15 minutes for all of the air in your home to be replaced by air from the outside. The number of air exchanges per hour, therefore, is a measure how much energy you will need to use in order to counter the effects of heat transfer via convection.

The proper way to measure the number of air exchanges per hour in your home is somewhat involved. It requires using air flow meter readings from various locations in your home. Since very few people have the necessary equipment to measure it exactly, we have developed a set of guidelines for estimating this factor. The table below gives you some idea as to the value for your home. You may need to interpolate between the values below to get the correct estimate for your home. For instance, if you have an average, insulated home that has been caulked and weather stripped in the last 4-5 years, you should probably select 1.0 as your value. However, if it has been about 8-10 years since you caulked or weatherstripped, you might want to choose something between 1.0 and 2.0 as the value.

Type of home	Air exchanges per hour
Old, un-insulated, weatherstripping not maintained	4.0
Old, un-insulated, weatherstripping maintained	2.0
Avg. insulated house, well maintained	1.0
New, well insulated house	0.5
New, super-insulated (12" walls)	0.2

The Second Law and Efficiency

Energy is also lost in our homes because of all of the energy transformations that are taking place there. The First Law of Thermodynamics tells us that the energy involved in any transfer must be conserved. This would seem to mean that we should never run out of energy and should pay no heed to anybody talking about energy being lost. The problem is that this is not the only law that governs energy transfers. While the total amount of energy does not change, the **Second Law of Thermodynamics** (see sidebar) puts limits on the amount of **usable energy** that can be transferred. One of the consequences of this law is that the total amount of usable energy that comes out of any process will be less than the total amount of energy that went into the process. The difference between the total amount of energy input and the usable energy output is expended as waste heat.

This brings us to the issue of efficiency, which is a measure of the amount of usable energy that is generated during any type of transfer. If a transfer is very efficient, then the amount of usable energy that is generated is almost equal to the total amount of energy that went into the transfer. This means that very little waste energy will be produced. An inefficient transfer, conversely, is one in which most of the energy going into the process is converted to waste heat. For example, a fluorescent light bulb converts about 20% of the electrical energy that runs through it into visible light energy. While this may not sound like a very efficient transfer, it is much better than the 5% efficiency of an incandescent light bulb, which most people use.

When discussing the efficiency of a process, we have to make sure and not forget all of the transfers that might need to take place in order to get to the one under investigation. A great example of this occurs when comparing the efficiencies of electric and internal combustion engine powered cars. The efficiency of the electric motor in a car is about 90%, while the efficiency of the internal combustion engine is only about 25%. However, these efficiencies are not the only things that need to be considered when comparing the two devices. How is the electricity that charges the car created? Where does the gasoline come from that powers the internal combustion engine? What types of transmission systems does each car have? There are many steps and energy transfers that take place in getting each type of car to move, and each one of these has its own individual efficiency. For instance, the average electric plant is only about 30-35% efficient in generating electricity (some newer natural gas plants are closer to 50-60%). This fact greatly reduces the overall efficiency of an electric car. When we consider the total efficiency, from getting the energy from its natural source to the car moving down the highway, we find that the electric car is only about 20% efficient, while the internal combustion engine automobile is about half that at 10%.

Second Law of Thermodynamics

There are many equivalent statements of the Second Law of Thermodynamics. Most often, people write about the consequences of the Second Law (Ex. "Heat will flow spontaneously from hot to cold", "No energy transfer can ever be 100% efficient", "A heat engine and a heat pump both require a hot and a cold reservoir"). An increasingly more uncommon way to write it is in mathematical terms. For example, old textbooks usually write it something like

In a closed system, the total entropy either increases or stays the same

The reason why most authors today are loathe to write this is that it is not particularly useful in this form and it requires a lot of explanation. First, one has to define the term "entropy", which is a fairly non-standard word. Entropy is actually the logarithm of the number of states accessible to a system and is defined by the equation

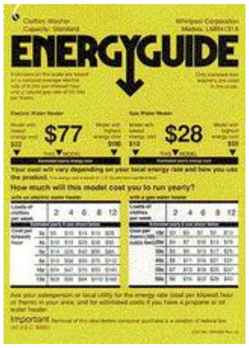
$$1/T = (dS/dU)_N$$

where T is the temperature, S is the entropy, U is the total energy of the system and $(dS/dU)_N$ is the partial derivative of the entropy with respect to energy while holding particle number fixed. If your brain has not exploded by reading this definition, and you are still reading, then you realize why most scientist just say "Entropy is a measure of the chaos of a system", which, in a way, it is (a chaotic system usually has more states accessible to it than a non-chaotic one).

Even if you are able to get past the entropy difficulty, you then have to explain what a closed system is (there are no real closed systems in the universe, just ones that are close) and why entropy would only increase or stay the same in such a system. After you have spent a great deal of time doing this, you realize that you might have just as well written one of the consequences of the Second Law (which are understandable by most people) and have called it a day. Which is exactly what we are going to do.

Energy Use in the Home

Appliances



The efficiency of all of the appliances in our homes affects how much money we spend and energy we use. While heating/cooling does consume the largest single amount of the energy budget of the average household, it does not consume the majority. Other appliances in the home consume over 50% of all of the energy. Almost every American home has some type of stove or range, while about 75% of them have a washer and dryer, 50% have a dishwasher, and 33% have a separate freezer from their refrigerator. All of these appliances, plus the heating/cooling systems, amounted to over 101 million Btu's of energy being consumed in the homes of America in the last year. Considering the inefficiencies of transporting energy to homes, the total amount of energy that had to be consumed in order to power our houses was over 170 million Btu's.

The amount of money consumed by an appliance depends on the type of fuel used by the appliance, the power of the appliance, and the length of time that the appliance is allowed to run. For instance, the average electric oven uses an average of about 2,000 watts of power to heat itself to a temperature of 350 ^{o}F. If it is run for 1 hour, then it will use an amount of energy equal to

Energy = Power x Time = 2,000 watts x 1 hour = 2,000 watt-hour = 2 kilowatt-hour

At the current rate of about $.08 per kWhr, this corresponds to a cost of about 16 cents. The average natural gas stove uses about 11,000 Btu/hr to maintain the same temperature. If you ran it for the same amount of time as the electric stove, it would consume an amount of energy equal to

Energy = Power x Time = 11,000 Btu/hr x 1 hour = 11,000 Btu

The current cost of natural gas is about $.70 per therm. One therm is equivalent to 100,000 Btu. Thus, the natural gas costs about $.000007 per Btu. This means that the cost of running the natural gas stove for 1 hour is about 7 cents.

In the calculator that we will be using to estimate energy usage in our homes, the power usage for gas appliances will be assumed to be the national average, while the power usage for electrical appliances will need to be entered. This is because some gas appliances do not list a power rating or have the information in a non-reachable place on the appliance. If you cannot find the information for your electrical appliances, use the average values that we have provided in the calculator.

Instructions

We are now ready to use the calculator to estimate the energy usage in your home. Before we begin, we must state a few simple facts about the calculator. The first of these is that the calculator will not include the cost of running all of the smaller appliances in the home. The reason for this is that the list of appliances that we would have to include would make the calculator very unwieldy to use, as you would either have to scroll down a very lengthy list of items or to click through many different web pages. If you wish to figure out how much these appliances will cost you to run them, simply multiply the power of the appliance (in kilowatts) times the number of hours that you use it during the year times the cost of electricity.

The second thing that we must state is that this estimate is only as good as the information that is entered into the computer. If you enter incorrect data, e.g. if you enter 1 air exchange per hour when the actual number is closer to 0.5, you might find that the estimated cost of energy for your home is radically different than what you actually pay. Lastly, we need to point out that the calculator that we will be using has several assumptions built into it. As we go through the instructions below, these assumptions will be pointed out. If these assumptions are not valid for your home, the estimates of your cost can be far from reality. In analyzing your data, you will need to keep these assumptions in mind in order to come to valid conclusions about the energy usage in your home

With this in mind, let us proceed to the calculator **AFTER YOU HAVE READ THE INSTRUCTIONS (https://grants.kennesaw.edu/esa21/docs/energycalculator.html.zip)**

1. The calculator comes in two parts, both of which are on the same page. You will need to finish the first section before proceeding to the second section. The first section concerns the measurements of your home that you took several weeks ago. You will notice that this section is laid out similar to the form that you filled out for each room of your home. There are two ways for you to enter the data for this section. One way would be to enter the data for each room of your home as it is listed on your worksheet(s). After typing this in, press the Calculate button that is on the left side of the screen. After the program makes the calculation, click the Next Set of Surfaces button to clear the room data. Enter the data for the next room, and proceed as above until all rooms are finished. The second way to fill in the data can only be used if the surfaces in your home are all the same (ex. all windows are double pane, all walls are R-factor 19 wall, all ceilings are R-factor 30, etc.). If this is the case, then you can add up all of the area for each component and enter it as if there were only one room.
2. After you finish entering the Conduction data, scroll down the page to the section entitled "Other Household Data".
3. From your drawings, you should be able to calculate the total area of all south-facing windows in your home that are not shaded from the outside. The reason why you need to know this data is that your south-facing windows are a source of solar energy. During the summer, each square foot of south-facing window will allow about 37 Btu/hr of solar energy into the house, unless it is blocked from entering the house outside of the window (curtains or shades on the inside of the window do not count as shade since they allow the energy into the home before blocking it). In the winter, this value is about 27 Btu/hr. Enter the area in the topmost text area of the section.
4. In the second slot, enter the total area of all east- and west-facing windows. While these windows do not allow sunshine into the house the entire day, they do allow solar energy in for half of the day. During the summer, this can be significant since the Sun will be further north in the sky throughout the day.
5. The next slot asks you for the square footage of the cooled and heated floor space in your home. You should be able to calculate this from your drawing.
6. The next slot asks for the average height of the ceilings in your home. In conjunction with the square footage of the floors of your home, these two numbers give us an estimate of the volume of air space in the home. This is the amount of air that must be heated and cooled as air is being exchanged with the outside environment.
7. The next two slots ask for the thermostat settings for both winter and summer. These temperatures will determine the rate at which heat is exchanged with the outside, and thus, how much cooling and heating are necessary. Two assumptions go into this calculation. The first one is that the thermostat is not being switched from this temperature setting, i.e. the thermostat is not a programmable thermostat. If you have such a thermostat, you will need to enter an average setting of your thermostat that will take into account the variability of the temperature in your home. For instance, if you set your thermostat in summer at 78 during the day and 72 at night, then you will probably want to enter 74 as your average temperature (while 75 might be the actual average, this does not take into account that the variation in temperature during the day actually lowers the average temperature difference between inside and outside). The second assumption in this calculation is that we are experiencing a normal year in outside temperatures.
8. The next slot asks you to enter the number of air exchanges per hour in your home. Refer to the first page of this module for help in estimating this number.
9. The next slot asks you to enter the number of people in the home. This number is needed, since human bodies produce heat. In the winter, this decreases the amount of heating that you will need; in the summer, it will increase the amount of cooling that you need.

10. The next slot asks you what type of ductwork you have for your heating system. If you have central heat, then you will have some type of ductwork to bring the heated air to each room. If this ductwork is insulated, then you need to enter 1 in the slot; if it is not insulated, then you need to enter 2. If you use a wood stove or a portable kerosene heater in your home, you have no ductwork, and should enter 0 in the slot.
11. The next slot asks you what type of heater that you have. This is important, since it will determine what type of fuel that you use and how efficient each type of heater is. We are assuming that a natural gas and propane heaters are 80% efficient, a resistive electric heater is 100% efficient, a heat pump is 250% efficient (remember our discussion about heat pumps in week three of this module), and a wood stove is 60% efficient. If your true efficiencies differ from this, it will cause some error in the estimates. In order to select the appropriate stove, please enter the corresponding number in the slot
12. The next slot asks for the type of air conditioner that you have. We have assumed that all air conditioners have a seasonal performance factor of 2.5. If you have no air conditioner, enter a 0 in the slot; for window units, enter 1; for a central air conditioning system, enter 2.
13. The next several slots deal with some of the major appliances in your home. Enter the appropriate data in each slot, including the number of hours each appliance is used in a typical week. We have assumed that all refrigerators and hot water heaters are always operating.
14. The last bit of data that you need to enter is the price of each fuel that you use. This data should be available from the energy supplier that you use. If it is not, we have provided an estimated average of current costs.
15. After completing all of this data, press the **Calculate Summary** button at the bottom of the page. The program should return the cost of energy in your home for the year. If you find that you wish to change any of the Other Household data (the second section), you may do so without having to go back and enter the Conduction data again. Merely change the data that you want, and then press the **Calculate Summary** button again. It will recalculate your costs with the new changes. If you wish to change something about the Conduction data, you will need to press the **New Energy Analysis** button, which will clear the entire calculator and allow you to begin over again.

Assignment

Your assignment for this exercise is to run the energy calculator for your residence, complete the questions listed on the activity sheet, and attach printouts of your runs of the energy calculator.

References

1 "A Look At Residential Energy Consumption in 1997", U.S. Department of Energy, November 1999.

ESA 21: Environmental Science Activities

Activity Sheet
Energy: Synthesis &
Analysis

Name:

Lecture Professor:

Attach copies of your runs of the energy calculator to this sheet.

Analysis:
Are the yearly electricity and natural gas costs reasonable for your home based on your experience? If not, can you think of any reasons to explain this discrepancy?

Calculating the effects of lifestyle changes:
Make the changes below in the calculator and see how they affect annual energy costs.

(a.) Lower the thermostat setting in the winter a few degrees below your current setting and elevate the summer setting by the same amount.

	Initial setting	New setting
Winter		
Summer		

Annual Energy Savings ($):

Would you make this change? Why or why not?

(b.) Reduce the number of hours you use your oven or dryer by a *reasonable* amount.

	Initial no. of hours	New no. of hours
Oven		
Dryer		

Annual Energy Savings ($):

Would you make this change? Why or why not?